EUMETSAT Satellite Application Facility on
Support to Operational Hydrology and Water Management
http://hsaf.meteoam.it/

Product Validation Report (PVR)
H27/H140

Revision History

Revision	Date	Author(s)	Description
0.1	2019/02/27	S. Hahn	First draft of PVR.
0.2	2019/04/05	F. Delogu, S. Gabellani, L. Brocca	Add statistics maps, pie charts, results and discussion of H27/H140 SM-DAS-3 validation.
0.3	2019/04/06	D. Fairbairn	Add corrections about datasets and time periods.

Table of Contents

List of Tables

List of Figures

List of Acronyms

ASAR Advanced Synthetic Aperture Radar (on Envisat)

ASAR GM ASAR Global Monitoring

ASCAT Advanced Scatterometer

ATBD Algorithm Theoretical Baseline Document

BUFR Binary Universal Form for the Representation of meteorological data

DORIS Doppler Orbitography and Radiopositioning Integrated by Satellite (on Envisat)

ECMWF European Centre for Medium-range Weather Forecasts

Envisat Environmental Satellite

ERS European Remote-sensing Satellite (1 and 2)

ESA European Space Agency

EUM Short for EUMETSAT

EUMETCast EUMETSAT's Broadcast System for Environment Data

EUMETSAT European Organisation for the Exploitation of Meteorological Satellites

FTP File Transfer Protocol

H SAF SAF on Support to Operational Hydrology and Water Management

Météo France National Meteorological Service of France

Metop Meteorological Operational Platform

NRT Near Real-Time

NWP Near Weather Prediction

PRD Product Requirements Document

PUM Product User Manual

PVR Product Validation Report

SAF Satellite Application Facility

SAR Synthetic Aperture Radar

SRTM Shuttle Radar Topography Mission

SZF Sigma Zero Full resolution

SZO Sigma Zero Operational (25 km spatial sampling)

SZR Sigma Zero Research (12.5 km spatial sampling)

TU Wien Technische Universität Wien (Vienna University of Technology)

WARP Soil Water Retrieval Package

WARP H WARP Hydrology

WARP NRT WARP Near Real-Time

ZAMG Zentralanstalt für Meteorologie und Geodynamic (National Meteorological Service of Austria)

1. Executive summary

The validation of the H27/H140 SM-DAS-3 (DR) is summarized in this document. The H27/H140 Product Validation Report (DR) gives an overview of the data sets and methods used to validate the DR. The analysis of the DR follows the guidelines described in the Product Validation Report [1]. The quality benchmarks are defined in the Product Requirements Document (PRD) [2]. All quality benchmarks were computed on a global basis and are presented globally (i.e. all valid results). The validation framework of the Python Toolbox for the Evaluation of Soil Moisture Observations (pytesmo[1]) has been used to perform the validation. More information on the DR can be found in the Product User Manual (PUM) [3] and Algorithm Theoretical Baseline Document (ATBD) [4].

2. Introduction

2.1. Purpose of the document

The Product Validation Report (PVR) is intended to provide a detailed description of the validation data sets, methods and results used to analyze the performance of the DR.

2.2. Targeted audience

This document mainly targets:

1. Users of remotely sensed soil moisture data sets who want to obtain an understanding of the quality and performance.
2. Remote sensing experts interested in the validation and error characterization of satellite soil moisture data sets.

3. Data sets

3.1. H27/H140 SM-DAS-3 DR

The H27/H140 SM-DAS-3 is a root zone soil moisture product retrieved from scatterometer Surface Soil Moisture (SSM) observations. The H27/H140 production chain uses an offline sequential based on a Land Data Assimilation System (LDAS) based on an Extended Kalman Filter (EKF) approach. The EKF constitutes the central component of the H27/H140 production chain. The H-TESSEL Land Surface Model is used to propagate in time and space the soil moisture information through the root zone, accounting for physiographic information (soil texture, orography), meteorological conditions and land surface processes such as for example soil evaporation and vegetation transpiration. Essentially the H27/H140 production suite retrieves root zone soil moisture from ERS1/2 Active Microwave Instruments and ASCAT-A surface soil moisture for the period from 1992 to 2016 (particularly H27 over 1992-2014 and H140 over 2015-2016). The H27/H140 production chain also uses screen level parameters close

[1] https://github.com/TUW-GEO/pytesmo

to the surface (2-meters temperature and relative humidity) to ensure consistency of the retrieved Scatterometer root zone and the near surface observed weather conditions. The system is driven by ERA-Interim atmospheric fields.

H27/H140 SM-DAS-3 is available for 4 layers (thicknesses 0.07, 0.21, 0.72 and 1.89 m) at a 24-hour time step, with a global daily coverage at 00:00 UTC. In validation framework only layer 1 (thickness 0.07 - var40) will be considered against other datasets. More information on the algorithm can be found in the Algorithm Theoretical Baseline Document (ATBD) v0.2 [4].

3.2. NOAH Global Land Data Assimilation System (GLDAS)

The NOAH model provided by the Global Land Data Assimilation System (GLDAS) contains atmospheric and land surface parameters stored on a regular global grid (spacing 0.25°). From 2000-ongoing, the GLDAS NOAH version 2.1 data set provides soil moisture at a 3-hourly temporal resolution (daily at 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00 and 21:00 UTC) [5]. The data is publicly available at GES DISC[2] (Goddard Earth Sciences Data and Information Services Center). Soil moisture estimates are evaluated in kg m^{-2} and need to be converted into volumetric units. Soil characteristics such as temperature and moisture are provided in four layers (depth: 0.00-0.10 m, 0.10-0.40 cm, 0.40-1.00 m and 1.00-2.00 m). The soil moisture parameter of the first layer is used for validation.

3.3. CCI Passive soil moisture

The Soil Moisture CCI project[3] is part of the ESA Programme on Global Monitoring of Essential Climate Variables (ECV), better known as the Climate Change Initiative (CCI). The CCI Programme wants to contribute to the data bases collecting ECVs required by GCOS (Global Climate Observing System) and other international parties. The objective of the Soil Moisture CCI is to produce the most complete and most consistent global soil moisture data record based on active and passive microwave sensors. The project focuses on C-band scatterometers (ERS-1/2 scatterometer, Metop ASCAT) and multi-frequency radiometers (SMMR, SSM/I, TMI, AMSR-E, Windsat) as these sensors are characterized by their high suitability for soil moisture retrieval and a long technological heritage [6].

The CCI Passive Soil Moisture product (v4.4) was generated by the VU University Amsterdam in collaboration with NASA based on passive microwave observations from Nimbus 7 SMMR, DMSP SSM/I, TRMM TMI, Aqua AMSR-E, Coriolis WindSat, and GCOM-W1 AMSR2. The ECV soil moisture production system generates soil moisture at a spatial resolution of approximately 25 × 25 km for top < 2 cm of the soil, expressed in volumetric units ($m^3 m^{-3}$).

4. Methods

4.1. Pre-processing

4.1.1. Quality check

Erroneous root zone soil moisture values needs to be masked out in certain time periods (e.g. snow cover, frozen soil).In addition, soil temperature (° Celsius) and Snow Water Equiv-

[2] https://disc.sci.gsfc.nasa.gov/datasets/GLDAS_NOAH025_3H_V2.1/summary?keywords=GLDAS
[3] http://www.esa-soilmoisture-cci.org

alent (SWE) (kg m^{-2}) from NOAH GLDAS are used to mask soil moisture measurements in case of soil temperature $< 4°$ Celsius and SWE > 0 kg m^{-2}.

4.1.2. Spatial-temporal collocation

All data sets needs to be spatially and temporally harmonized before the quality benchmarks can be computed. The DR is used as a spatial reference (WARP 5 grid [7]) and all other data sets are collocated using the nearest neighbor in close proximity (maximum 85 km). Due to differences in the spatial resolution it is also possible that the same point is collocated more than once on the spatial reference grid.

The collocation in the temporal domain depends on the measurement frequency and interval. The time stamp information in the DR product is used as a temporal reference and the nearest measurement in close proximity (maximum 8 hours) from the validation data sets is used for collocation. Due to the time window and the temporal resolution of the data sets duplicated collocations are almost impossible.

4.1.3. Model resolution vs. observation resolution

The data sets in the validation procedure were not corrected for a mismatch in the observation depth (vertical resolution), which is also the case for a mismatch in spatial resolution.

The data sets were not further changed/adapted for the followings reasons:

- The penetration depth of the C-band microwave signal into the soil (depending soil surface conditions) is just a few centimeter (1-2 cm), but could also be deeper in very dry soil regimes. A spatial/temporal determination of the penetration depth is not straightforward and therefore no assumptions have been made regarding the observation depth.
- A mismatch of representativeness (spatial resolution, vertical resolution (i.e. observation depth)) is part of the validation process of products and, if not properly accounted for, included in the performance metric. We wanted to validate the original surface soil moisture values/signal, even if this means a higher error due to a mismatch in vertical representativeness.

4.2. Quality benchmarks

The validation has been performed globally for the time period 2007-06-01 until 2016-12-31 on the WARP 5 grid [7]. As reference data set the NOAH GLDAS land surface model (v2.1) and the passive CCI soil moisture product (v4.4) were used. The first soil moisture layer (0.00 - 0.10 m) of NOAH GLDAS was used for the validation.

The Signal-to-Noise Ratio (SNR) [8] and the Pearson correlation coefficient (R) have been computed globally. The Triple Collocation Analysis (TCA) has been performed between H27/H140 SM-DAS-3, NOAH GLDAS and the passive CCI soil moisture product, whereas R was only computed between H27/H140 and NOAH GLDAS.

5. Results and discussion - H27/H140 SNR and Pearson R

The quality benchmarks have been computed only on a global basis, but under certain circumstances (e.g. number of valid measurements < 10) no results have been obtained. In addition,

locations with a p-value > 0.05 (i.e. insignificant Pearson correlation coefficient) have been discarded.

The following Boxplot in Figure 5.1 summarizes the distribution of the quality benchmarks. The whisker indicate the 5th and 95th percentile, whereas the size of the box represents the Inter Quartile Range (IQR). A percentage indicating the number of locations exceeding the threshold/target/optimal requirements is given as well. As can be seen in Figure 5.1a, more than 54% of the valid global validation results are above the SNR target threshold (SNR > 3 dB). In other words, the soil moisture signal variance is more than twice compared to the noise variance in this case. A SNR above the optimal threshold (SNR > 6 dB) indicates that the soil moisture signal variance is more than four times higher than the noise variance. The same inverse relationship between the signal variance and noise variance is true for negative values of SNR. Hence, -3 dB and -6 dB correspond to a situation where the signal variance is only a half or a quarter compared to the noise variance. The Boxplot of Pearson R in Figure 5.1b illustrates that more than 80% of global results are above the threshold (R > 0.5). Negative correlations are also presented and related to soil moisture retrieval problems in desert regions (see ATBD [4]). Many locations reach the optimal threshold for Pearson R (R > 0.8). Finally, the global product area shows overall acceptable results of Pearson R.

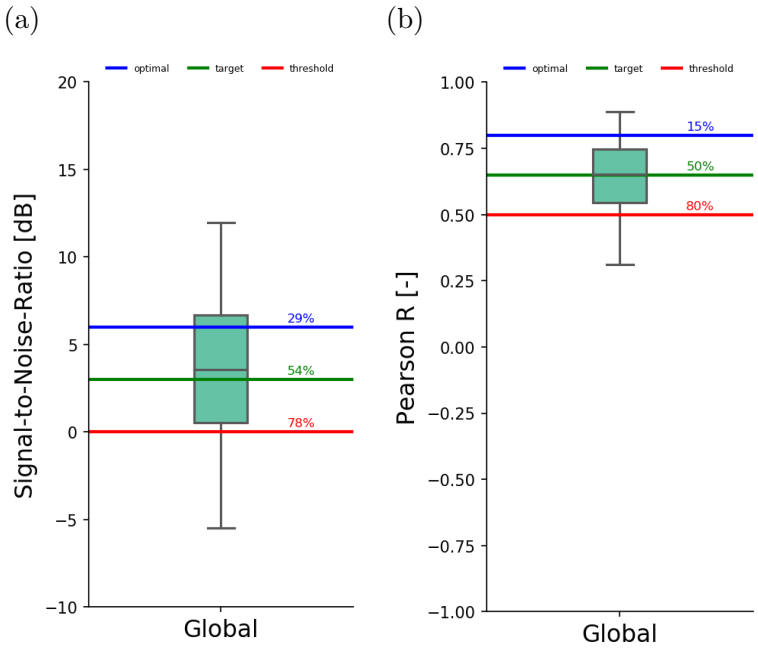

Figure 5.1: The boxplots indicate the distribution of the quality benchmarks globally. A percentage of locations exceeding each of the three thresholds is indicated as well.

Global map of SNR are shown in Figure 5.2. The best performing areas are the Sahel zone in Africa, India, Western Australia, parts of Brazil, Argentina, southern Europe, southern Africa, Mexico and United States, as well as central Asia. Relating these areas to vegetation and climate zones, grassland and (semi-)arid climate conditions strongly correlate. On the other hand, it appears that the SNR performance generally deteriorates in very dry environments. As

expected, many of these regions results get worse (see Figure 5.2. The remaining regions below 0 dB are mostly North America, western Australia and parts of Europe. No valid results have been obtained for almost 20% of the global product. Furthermore, it is evident that some areas (about 20%) show a SNR below the 0 dB threshold, but also roughly 60% are above the 0 dB threshold. No results are shown for tropical forests, mountainous regions and wetlands, because these areas are filtered during the quality assessment.

(a)

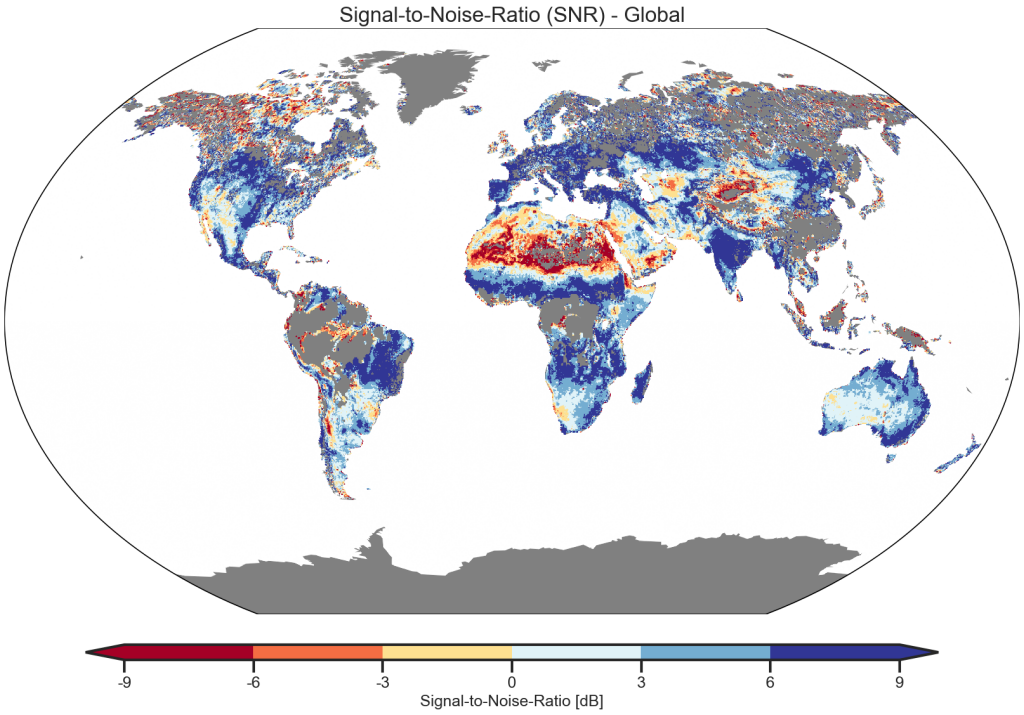

Figure 5.2: The global maps (global (a) show the Signal-to-Noise-Ratio (SNR) expressed in dB for the H27/H140 SM-DAS-3 DR.

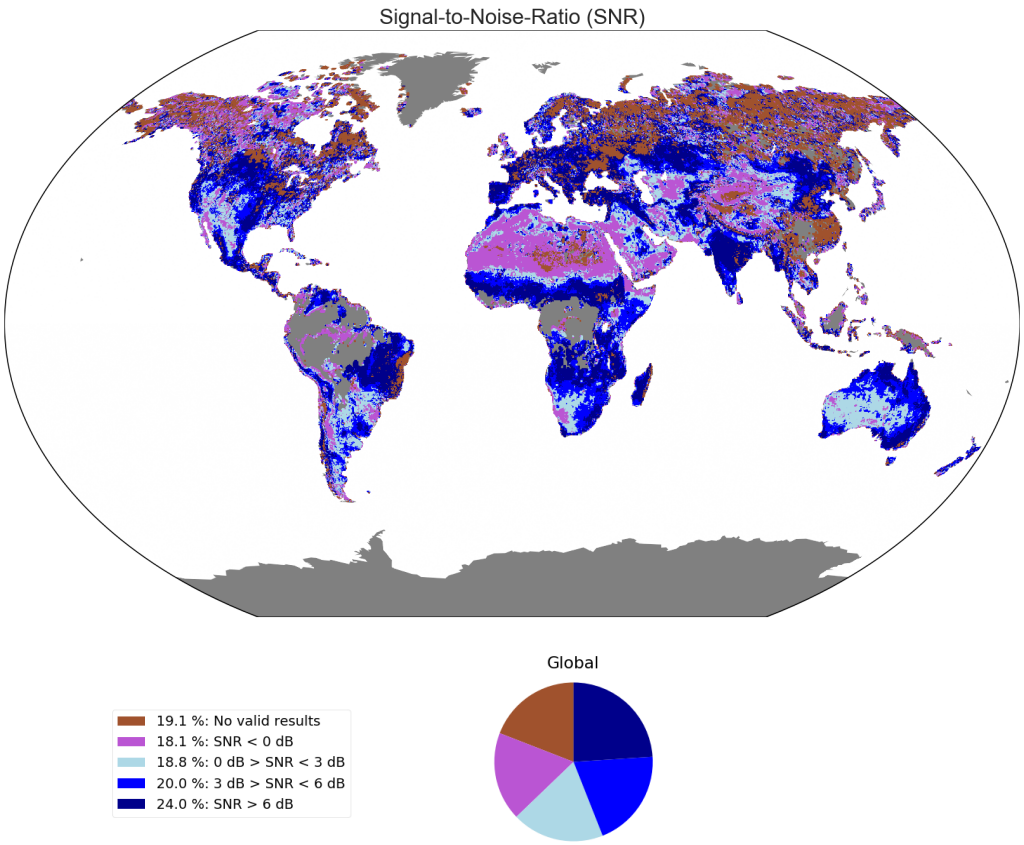

Figure 5.3: Summary of validation results of H27/H140 DR for the period 2007-01-01 until 2016-12-31. The percentage of non-valid and valid results is for global product area. The valid results are further divided into the pre-defined thresholds. The map on top depicts the spatial distribution of the different groups

Global map of the Pearson correlation coefficient are shown in Figure 5.4. Similar to SNR, the best performing areas are the Sahel zone in Africa, India, Western Australia, parts of Brazil, Argentina, southern Europe, southern Africa, Mexico and United States, as well as central Asia. Negative correlations are also noticeable and related to soil moisture retrieval problems in desert regions (see ATBD [4]). Overall, the Pearson R results indicate consistent spatial pattern compared to SNR. A map of Pearson R for global results can be found in Figure 5.5. No valid results have been obtained for about 2% of global product. Furthermore, it is evident that some areas (about 20%) show a R below the 0.5 threshold, but more than 70% are above the 0.5 threshold. No results are shown for tropical forests, mountainous regions and wetlands, because these areas are filtered during the quality assessment.

(a)

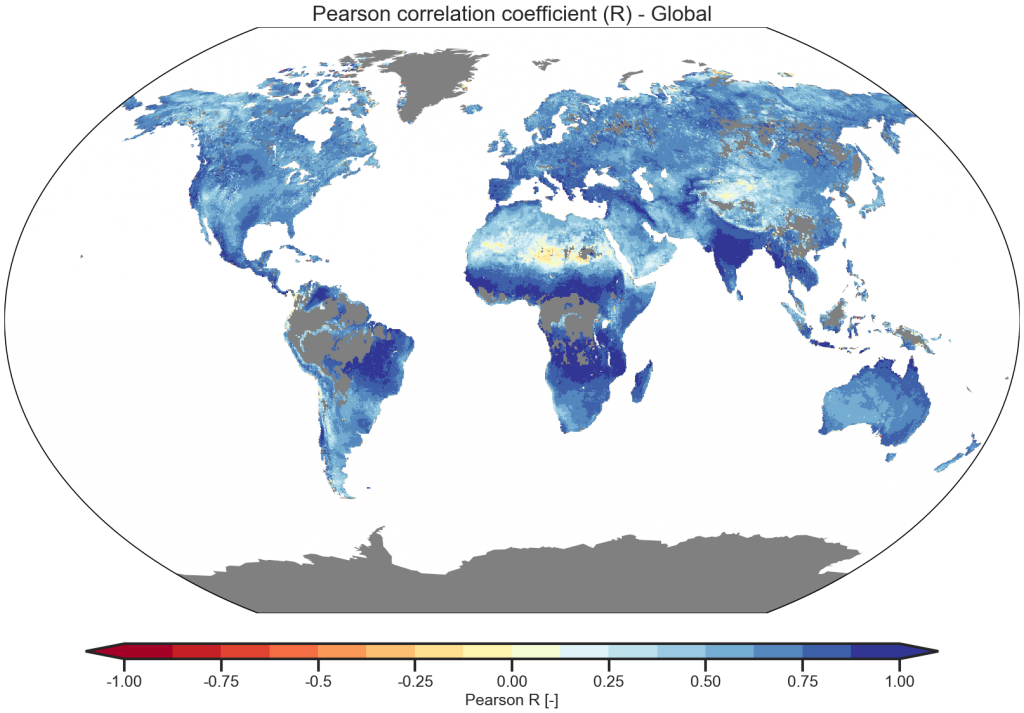

Figure 5.4: The global maps (global (a) show the Pearson correlation coefficient for the H27/H140 root zone soil moisture DR.

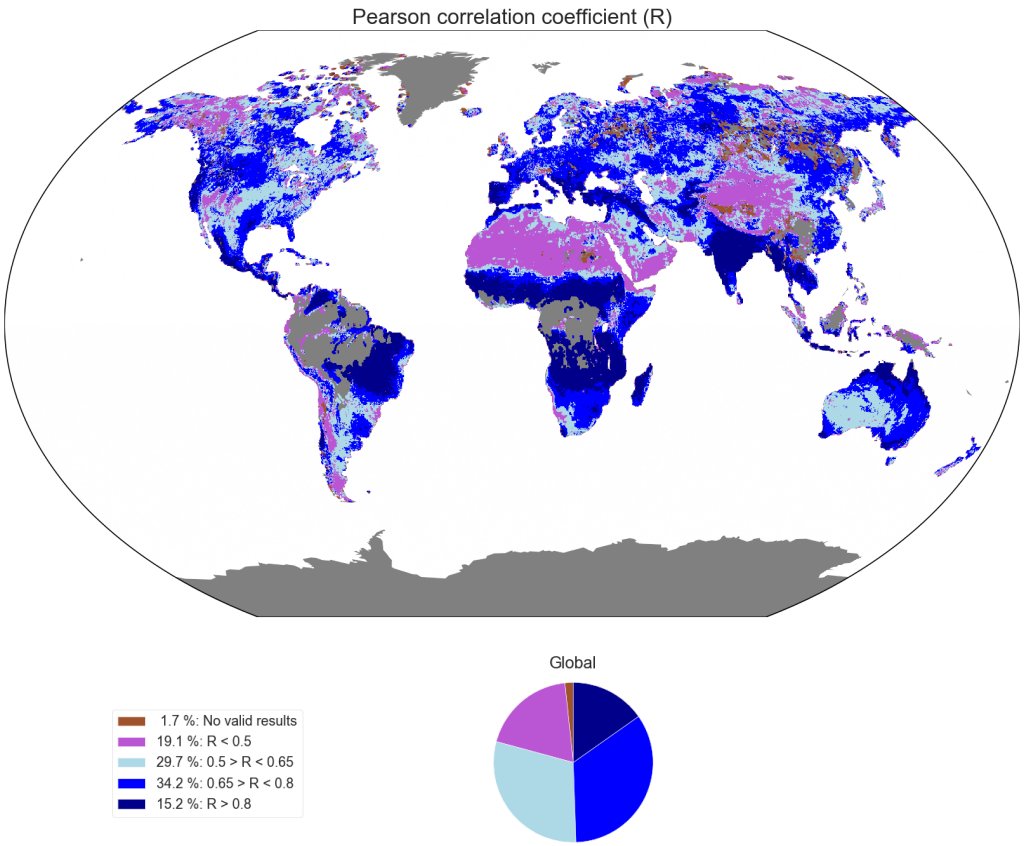

Figure 5.5: Summary of validation results of H27/H140 DR for the period 2007-01-01 until 2016-12-31. The percentage of non-valid is shown for global map. The valid results are further divided into the pre-defined thresholds. The map on top depicts the spatial distribution of the different groups.

6. Summary and conclusion

In general, the validation results indicate a good performance for global product, except for parts of North America, Northern Europe and Eastern Australia. On a global scale, a lower performance of the H27/H140 DR can be found in areas with low soil moisture dynamics (e.g. deserts) or at higher latitudes (see Figure 5.2 and Figure 5.3). In the latter case, frozen soil and snow cover make it difficult to retrieve reliable soil moisture information.

Therefore, in these regions only summer months can be used for validation. Looking at the distribution of the results and comparing them against the threshold/target/optimal requirement shows that more than 75% (SNR) and 80% (Pearson R) of the locations are exceeding the minimal threshold (see Figure 5.1). Only a small percentage of regions (SNR 22% and Pearson R 20%) are below the minimal threshold requirements.

7. References

[1] "Product Validation Report (PVR) Root Zone Soil Moisture Data Records, for products H27 and H140," Tech. Rep. Doc. No: SAF/HSAF/CDOP2/PVR, v0.5, 2017.

[2] "Product Requirements Document (PRD)," Tech. Rep. Doc. No: SAF/HSAF/CDOP3/PRD, v0.1, 2017.

[3] "Product User Manual (PUM) Root Zone Soil Moisture Data Records, for products H27 and H140," Tech. Rep. Doc. No: SAF/HSAF/CDOP2/PUM, v0.2.

[4] "Algorithm Theoretical Baseline Document (ATBD) Root Zone Soil Moisture Data Records, for products H27 and H140," Tech. Rep. Doc. No: SAF/HSAF/CDOP3/ATBD, v0.6, 2018.

[5] M. Rodell, P. R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C.-J. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J. K. Entin*, J. P. Walker, D. Lohmann, and D. Toll, "The Global Land Data Assimilation System," *Bulletin of the American Meteorological Society*, vol. 85, pp. 381–394, Mar. 2004.

[6] W. Wagner, W. Dorigo, R. de Jeu, D. Fernandez, J. Benveniste, E. Haas, and M. Ertl, "Fusion of active and passive microwave observations to create an essential climate variable data record on soil moisture," in *Proceedings of the XXII International Society for Photogrammetry and Remote Sensing (ISPRS) Congress, Melbourne, Australia*, vol. 25, 2012.

[7] "WARP 5 Grid," Tech. Rep. v0.3, 2013.

[8] A. Gruber, C.-H. Su, S. Zwieback, W. Crow, W. Dorigo, and W. Wagner, "Recent advances in (soil moisture) triple collocation analysis," *International Journal of Applied Earth Observation and Geoinformation*, vol. 45, pp. 200–211, Mar. 2016.

Appendices

A. Introduction to H SAF

H SAF is part of the distributed application ground segment of the "European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)". The application ground segment consists of a Central Application Facilities located at EUMETSAT Headquarters, and a network of eight "Satellite Application Facilities (SAFs)", located and managed by EUMETSAT Member States and dedicated to development and operational activities to provide satellite-derived data to support specific user communities (see Figure A.1):

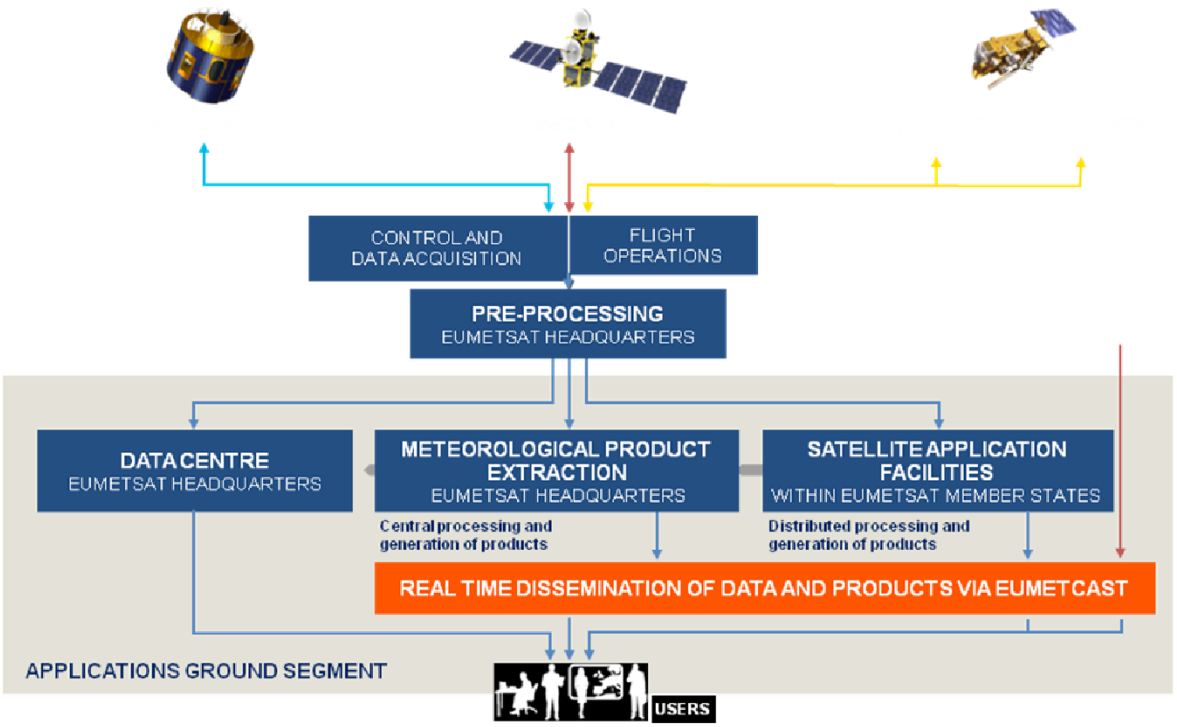

Figure A.1: Conceptual scheme of the EUMETSAT Application Ground Segment.

Figure A.2 here following depicts the composition of the EUMETSAT SAF network, with the indication of each SAF's specific theme and Leading Entity.

B. Purpose of the H SAF

The main objectives of H SAF are:

a) to provide new satellite-derived products from existing and future satellites with sufficient time and space resolution to satisfy the needs of operational hydrology, by generating, centralizing, archiving and disseminating the identified products:

- precipitation (liquid, solid, rate, accumulated);
- soil moisture (at large-scale, at local-scale, at surface, in the roots region);

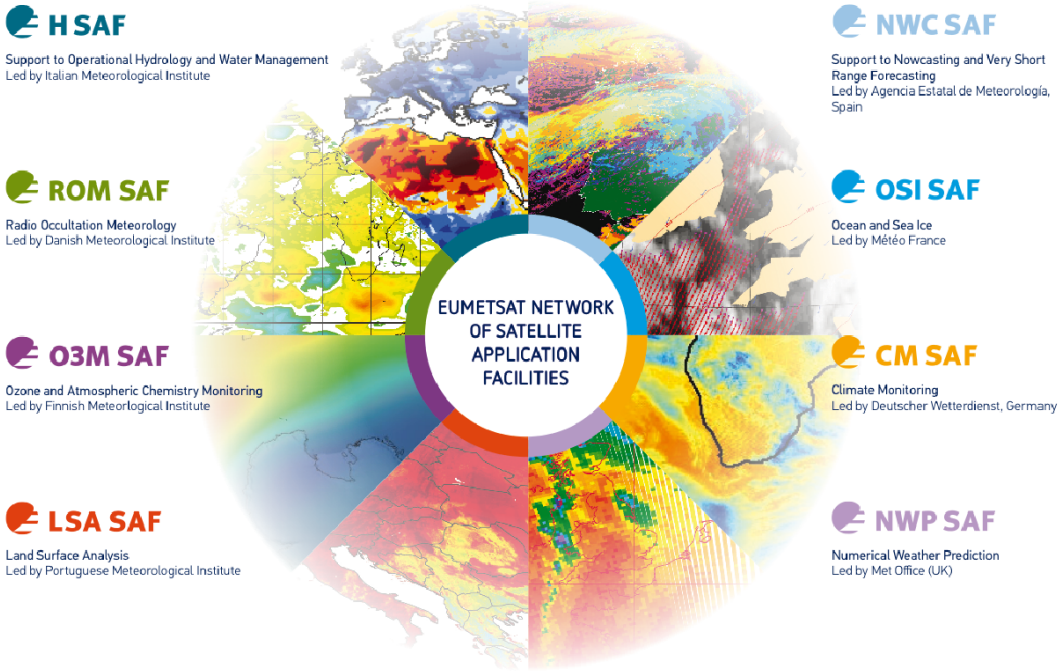

Figure A.2: Current composition of the EUMETSAT SAF Network.

- snow parameters (detection, cover, melting conditions, water equivalent);

b) to perform independent validation of the usefulness of the products for fighting against floods, landslides, avalanches, and evaluating water resources; the activity includes:

- downscaling/upscaling modelling from observed/predicted fields to basin level;
- fusion of satellite-derived measurements with data from radar and raingauge networks;
- assimilation of satellite-derived products in hydrological models;
- assessment of the impact of the new satellite-derived products on hydrological applications.

C. Products / Deliveries of the H SAF

For the full list of the Operational products delivered by H SAF, and for details on their characteristics, please see H SAF website hsaf.meteoam.it. All products are available via EUMETSAT data delivery service (EUMETCast[4]), or via ftp download; they are also published in the H SAF website[5].

All intellectual property rights of the H SAF products belong to EUMETSAT. The use of these products is granted to every interested user, free of charge. If you wish to use these products, EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.

[4] http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/index.html
[5] http://hsaf.meteoam.it

D. System Overview

H SAF is lead by the Italian Air Force Meteorological Service (ITAF MET) and carried on by a consortium of 21 members from 11 countries (see website: hsaf.meteoam.it for details)

Following major areas can be distinguished within the H SAF system context:

- Product generation area
- Central Services area (for data archiving, dissemination, catalogue and any other centralized services)
- Validation services area which includes Quality Monitoring/Assessment and Hydrological Impact Validation.

Products generation area is composed of 5 processing centres physically deployed in 5 different countries; these are:

- for precipitation products: ITAF CNMCA (Italy)
- for soil moisture products: ZAMG (Austria), ECMWF (UK)
- for snow products: TSMS (Turkey), FMI (Finland)

Central area provides systems for archiving and dissemination; located at ITAF CNMCA (Italy), it is interfaced with the production area through a front-end, in charge of product collecting. A central archive is aimed to the maintenance of the H SAF products; it is also located at ITAF CNMCA.

Validation services provided by H SAF consists of:

- Hydrovalidation of the products using models (hydrological impact assessment);
- Product validation (Quality Assessment and Monitoring).

Both services are based on country-specific activities such as impact studies (for hydrological study) or product validation and value assessment. Hydrovalidation service is coordinated by IMWM (Poland), whilst Quality Assessment and Monitoring service is coordinated by DPC (Italy): The Services activities are performed by experts from the national meteorological and hydrological Institutes of Austria, Belgium, Bulgaria, Finland, France, Germany, Hungary, Italy, Poland, Slovakia, Turkey, and from ECMWF.